PERGAMON

Vision Research 38 (1998) 2047–2052

Vision Research

Visual acuity versus letter contrast sensitivity in early cataract

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Received 19 February 1997; received in revised form 11 July 1997

Abstract

Large and small letter contrast sensitivity and visual acuity were assessed in 37 elderly eyes (mean VA −0.01 logMAR, Snellen 6/6) and their lens opacities were categorised and graded using the LOCS III system. Large letter contrast sensitivity was often not reduced in cataract from age-matched normal values and provided limited information. Small letter contrast sensitivity was shown to be a more sensitive measure of early cataract than visual acuity and large letter contrast sensitivity. Its usefulness may be limited by its strong correlation with visual acuity ($r^2 = 0.70$), which is the standard and traditional measure of vision in cataract.

Keywords: Contrast sensitivity; Spatial frequency; Visual acuity; Cataract; Vision loss

1. Introduction

Visual acuity (VA) is the traditional standard measurement of visual function in cataract. However, some cataract patients can retain relatively good VA, yet complain of poor vision. It has been suggested that VA provides an inadequate assessment of vision in these patients and other tests of vision, such as contrast sensitivity (CS), should be measured in addition to VA [1–6]. However, other studies have suggested that CS provides little useful information beyond VA about vision in cataract [7–9]. There is further disagreement regarding what spatial frequency or target size should be used to measure CS in cataract patients. Some studies suggest that CS should be measured at low spatial frequencies in cataract [1,3–5]. Other studies have suggested that high spatial frequency CS provides more information [2,10,7]. In this study, we compared the sensitivity of large (assessing predominantly low spatial frequency CS) and small letter CS tests (assessing predominantly high spatial frequencies) and VA to early cataract. Letter targets were used as they are becoming increasingly popular for clinical CS measurements [11,3,12,4,5,13–15]. Two of the studies [7,9] that suggested that CS provided information of little value in cataract patients used subjects with very early cataract (mean logMAR VAs of −0.07, Snellen 6/5 and 0.07, Snellen $6/6^{-3}$, respectively). For that reason we used a similar sample in this study.

2. Methods

Subjects were recruited from several local ophthalmologists' offices in the Waterloo area and from the staff and patient population of the School of Optometry. Potential subjects gave written informed consent prior to the study. The tenets of the Declaration of Helsinki were followed and the study gained ethical approval from the Office of Human Research, University of Waterloo. Potential subjects were over 60 years of age with either relatively clear lenses or early cataract and no other co-morbid eye disease. Subjects were excluded from the study if they had poor general health, diabetes mellitus, refractive errors greater than ±6.00 DS, visual acuity worse than 6/9 and a history of amblyopia or ophthalmic surgery. Subjects were screened for ocular diseases by ophthalmoscopy and slit-lamp biomicroscopy. In all cases, the eye with the better VA was chosen according to the VA recorded in the clinical files. VA and CS measurements were made on 37 eyes of 37 subjects.

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0042-6989/98/$19.00
PII: S0042-6989(97)00382-9

A logMAR VA chart consisting of high contrast (Weber contrast 97%) black letters was displayed on a high resolution video monitor of luminance 80 cd/m^2. The testing distance was 6 m. The chart used the following design features of the Bailey-Lovie VA chart:

1. Similar legibility letters: The series of ten 5x4 non-serif letters adopted in 1968 by the British Standards Institution were used.
2. The same number of letters per acuity row: five letters.
3. Uniform between-letter and between-row spacing: The between-letter spacing was equal to one letter-width and the between-row spacing was equal to one letter-height of the underlying row.
4. Equal logarithmic progression of letter size: 0.1 logMAR steps.

The letters presented on the video monitor ranged from 0.50 logMAR (6/19 Snellen) to -0.20 log MAR (6/3.8 Snellen). A by-letter scoring system was used (0.02 logMAR per letter).

A small letter CS test that was similar in design to that used by Rabin [13] could also be displayed on the video monitor. The letters were all the same size (0.13° or 0.2 logMAR (6/9 Snellen) at a viewing distance of 6 m) and reduced in contrast in 0.1 log CS steps from 0.0 to 1.6 log CS. Letters have a broad spatial frequency spectrum, but the most important frequency of a letter is thought to be ≈ 2 cycles per letter width [16,17]. For 0.13° letters this is 15.4 c/deg. The letter CS chart followed the design features of the VA chart as far as possible: The same ten letters were used (although different letter sequences were used for all three tests); five letters on each line with equal contrast; a 0.1 logarithmic progression of CS; uniform between-letter spacing and the same by-letter scoring system in which credit (0.02 log CS) was given for each individual letter read correctly. Only one line of letters was displayed on the monitor at any one time. The lower contrasts were obtained by dithering. That is some of the pixels in the letter were 'grey' while others were 'white'. This is easily achieved in most draw programs for the Mac by using the various patterns. In this case we used one pattern where one of every four pixels was grey and the remainder white. The second pattern was a 'one in eight'. For the first pattern the mean luminance of the pattern is calculated as (3*l (white) + 1*l (grey))/4. This has the effect of reducing the Weber contrast of the letter by a factor of 4 or 0.6 log units. The one in eight pattern has the same effect except the Weber contrast of the letter is reduced by a factor of 8 or 0.9 log units. These theoretical predictions were confirmed by extensive and careful photometry. The luminance and contrast of the charts were checked regularly using a photometer (Minolta chroma meter CS-100) and kept constant throughout the study. Contrast was maintained within ± 0.02 log unit of the nominal values.

Large letter CS was measured by using the same letter CS test as described above and reducing the viewing distance from 6m to 1m. This also made the large letter CS measurements similar to those obtained with the Pelli–Robson chart [11] which uses a 1 m working distance. The letters subtended 0.79° or 0.98 logMAR at the 1 m viewing distance. The 2 cycles/letter formula [16,17] suggests that the most important spatial frequency content of these letters is ≈ 2.5 c/deg.

All the measurements were performed in a dimly lit room and all the tests were conducted monocularly, using the natural pupil and the best correction obtained after refraction using spherical and cylindrical lenses. Full aperture trial lenses were used and working distance lenses were incorporated when necessary. The order of measurement was randomised. The subjects were instructed to read each chart as far down as possible and were encouraged to guess.

Subsequent to VA and CS measurements, the subjects were dilated with 0.5% Tropicamide and the lenses were classified and graded according to the Lens Opacities Classification System III (LOCS III; [18]).

3. Results

The 37 eyes were subsequently divided into a cataract and age-matched control group using the LOCS III system. Increased light scatter is a normal consequence of ageing and there is no obvious point at which this increased light scatter becomes cataract. The following inclusion criteria were used to place lenses into a 'cataract' group: a lens opacity above level 2.0 of the LOCS III system for cortical and nuclear cataract. Cortical and nuclear cataracts of LOCS grade 2.0 or less has been shown to have negligible effects on Pelli–Robson CS and Vistech disability glare [19]. A lens that contained any posterior subcapsular cataract (PSC) was placed into the cataract group. This was because PSC, even in the early stages, can have a dramatic effect on vision [20,21,19]. There were 18 eyes in the cataract group (mean age $\pm$ 1 S.D: 71.33 $\pm$ 4.45) and 19 eyes in the age-matched control group (mean age $\pm$ 1 S.D.: 68.58 $\pm$ 4.91). There was no significant difference between the ages of subjects in the two groups (unpaired t-test, $t = 1.79$, $P > 0.05$). The mean values ($\pm$ 1 S.D.) for each test procedure in both control and cataract subject groups are shown in Table 1. An ANOVA indicated that the large letter CS and small letter CS results were significantly different from each other ($P <$ < 0.001) and that both scores were significantly worse in the cataract group compared to control ($P < 0.001$). A significant interaction effect ($P < 0.001$) showed that the difference in CS between cataract and age-matched control groups was significantly greater for small letter CS than for large letter CS.

The standard deviation values in Table 1 indicate that the CS measurements, particularly the small letter CS measure, were more variable than VA. Z-scores were used to standardise measurements with respect to variability and to put CS and VA scores in the same units. They were calculated as the difference in mean values between the control and cataract groups divided by the standard deviation of the control group. The z-scores for small letter CS, large letter CS and logMAR VA were 2.73, 1.73 and 2.19, respectively. Another indication of the discriminative ability of the tests was determined from the number of scores from the 18 cataract subjects that were outside the 95% confidence limits for the normal group. These were nine (VA), 13 (small letter CS) and four (large letter CS). Five small letter CS test scores were abnormal in subjects with normal VA.

The majority of the lenses contained pure nuclear opacity ($n = 19$) or predominantly nuclear cataract with cortical grade ≤ 1.0 ($n = 8$) or cortical grade ≤ 2.0 ($n = 3$). There were four lenses of predominantly cortical cataract and three lenses containing posterior subcapsular cataract. The log CS and logMAR VA values are plotted as a function of nuclear lens grading scores in Fig. 1. These include data from lenses that were predominantly nuclear but contained a small amount of cortical cataract (less than grade 2.0). Cortical cataract of LOCS grade 2.0 or less has been shown to have negligible effects on Pelli–Robson CS and Vistech disability glare [19]. The seven lenses that were either predominantly cortical or contained PSC cataract were not included in this analysis. As expected, all three tests show worsening performance with increasing opacity (Fig. 1). A plot of logMAR VA versus opacity grade shows a positive slope, because higher logMAR VA represents poorer visual function. The regression equation for small letter CS vs. nuclear cataract grade had a high r^2 value (0.58) and steep slope (slope value -0.35). The r^2 and slope values from the equations of nuclear grade versus the other two tests were substantially lower (r^2 values of 0.37 and 0.47 and slope values of -0.12 and 0.09 for large letter CS and VA, respectively). The amount of change in VA and CS for a one

Table 1
Means $\pm$ 1 S.D. of 18 cataract subjects and 19 age-matched control subjects for small letter contrast sensitivity, large letter contrast sensitivity and logMAR VA

Vision tests	Control	Cataract
Small letter log CS	0.980 ± 0.134	0.614 ± 0.214
Large letter log CS	1.765 ± 0.084	1.620 ± 0.086
LogMAR VA	-0.062 ± 0.047 (Snellen $6/5^{-1}$)	0.041 ± 0.069 (Snellen $6/6^{-2}$)

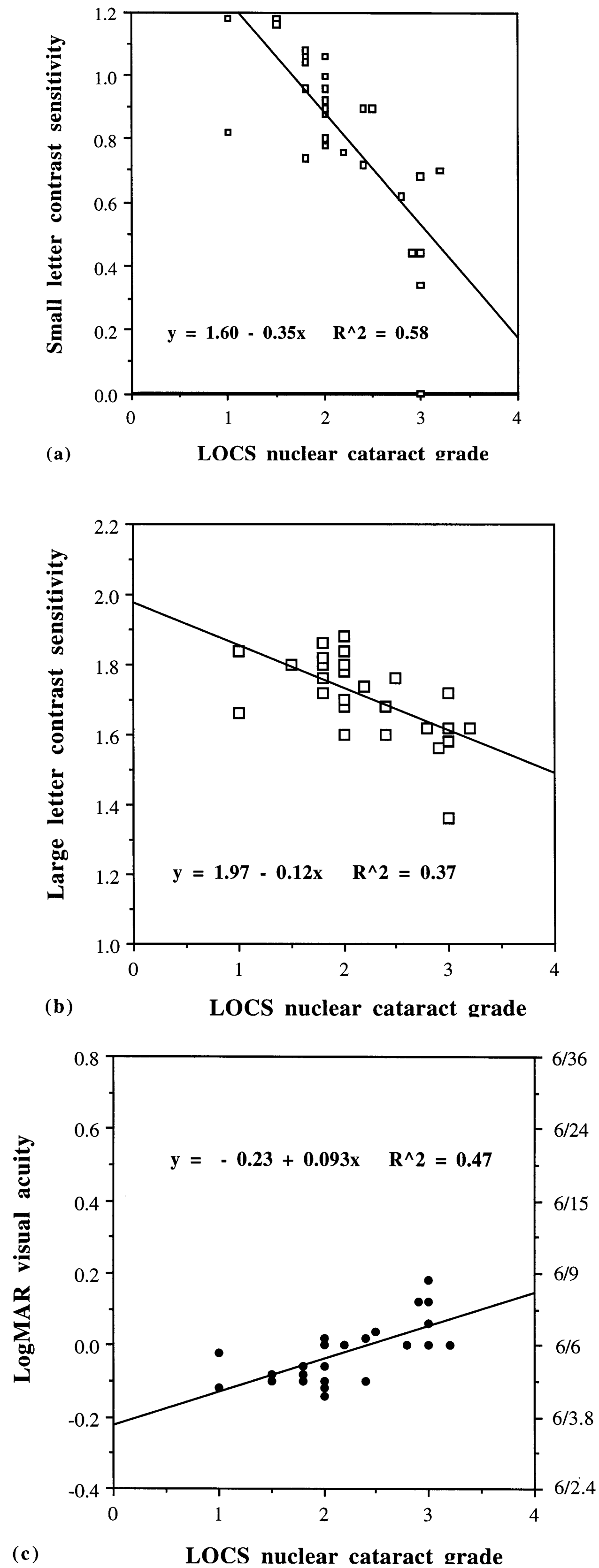

Fig. 1. Nuclear cataract grades as determined by LOCS III plotted against (a) small letter contrast sensitivity; (b) large letter contrast sensitivity; (c) logMAR VA.

step change in LOCS III was determined from the regression equations of LOCS III vs. VA and CS. This amount of change has been termed a 'clinically significant change' by Chylack et al. [9]. Clinically significant changes for small letter CS, large letter CS and logMAR VA were 0.35 log CS, 0.12 log CS and 0.09 logMAR.

There were highly significant relationships between the three measures with r^2 values of 0.70 (small letter CS versus VA), 0.38 (large letter CS versus VA) and 0.40 (small letter CS versus large letter CS). To determine whether either of the two CS measures provided additional information beyond VA about cataract related changes in vision, we performed a stepwise regression analysis between nuclear grade and the vision tests, using VA as a forced first step in the regression model. This analysis indicated that small letter CS was providing statistically significant extra information beyond VA about cataract extent. It increased the percentage of the variance of the nuclear grade data accounted for from 47% (VA alone) to 59% (VA and small letter CS). This was not significantly affected if age was also included in the model with the percentage variance accounted for increasing from 51% (VA and age) to 63% (VA, age and small letter CS). If small letter CS was forced as the first step in the model, the other two measures provided no significant additional information about nuclear grade. If large letter CS was forced as the first step in the model, small letter CS was indicated as the second and last step in the model and increased the percentage variance accounted for from 37% to 62%.

It could be argued that as one of the exclusion criteria was a VA worse than 6/9, a bias could be introduced into the study which would reduce the association between VA and cataract grade compared to the association between CS and cataract grade. However, after reanalysing the data using a contrast sensitivity exclusion criteria of worse than 0.50 log units (which removed a further four subjects), the trend of the results remained the same. This is likely due to the very close association between small letter CS and VA ($r^2 = 0.70$), so that removing those with relatively poor CS also removed those with relatively poor VA.

4. Discussion

There was little if any large letter CS loss in many of the cataract subjects. Only four of the 18 cataract subjects showed a large letter CS lower than the 95% confidence limits of the control group. The difference between the mean CS of the cataract and control groups was 0.145 log CS for the large letter CS test and 0.366 for the small letter CS test. Even after correction of variability using z-scores, the large letter CS test showed much less difference between the cataract and control group means (1.73 S.D.s) than small letter CS (2.73 S.D.s) or VA (2.19 S.D.s). The lower sensitivity and discriminative ability of the large letter CS are similar to previous findings of a poor sensitivity of the Pelli–Robson letter CS chart to very early cataract [19,22,8]. These results reflect the attenuation of CS at predominantly high spatial frequencies in very early cataract with lower spatial frequencies being relatively unaffected (e.g. [1,20,10,6]. Studies which have concluded that low spatial frequency CS is of little value in cataract assessment have used samples containing very early cataract (e.g. a mean logMAR VA of -0.07, 6/5 Snellen; [7]). The present study agrees with the findings of these reports and used a similar sample of subjects with a mean logMAR VA of -0.01, 6/6 Snellen. Using a larger sample and determining clinically significant changes (the amount of change per LOCS grade) for several different types of cataract morphology, Chylack et al. [9] reported clinically significant changes of 0.04–0.07 logMAR VA and 0.02–0.07 log CS using a 2 c/deg sine-wave grating test. We found similar, although slightly larger values for logMAR VA (0.09) and large letter CS (0.12). Our results agree with Chylack et al.'s [9] findings that when assessing patients with very early cataracts, such as those used in anti-cataract drug trials, low spatial frequency CS measurements are of very limited value.

Reports that low spatial frequency CS measurements provide valuable information have used subjects with cataract of a slightly later stage (suggested by mean sample logMAR VAs of 0.29, 6/12 Snellen; [5]; 0.19 logMAR, 6/9 Snellen; [23]). Lower spatial frequency CS becomes increasingly reduced with later stages of cataract [20,10] and measurements such as provided by the Pelli–Robson chart are likely to be of value in patients with somewhat more advanced cataract [23,19,5]. Lasa et al. [19] suggested that the Pelli–Robson CS was reduced in patients with greater than cortical and nuclear LOCS grade 2 and PSC grade 1.

All analyses indicated that the small letter CS test was more sensitive to early cataractous change than either large letter CS or VA. Among the three tests, the small letter CS exposed the greatest difference between cataract and controls (0.37 log units or over three lines on the CS chart). By comparison, the logMAR VA difference between these groups was ≈ 0.10 log units or one line on the VA chart. Similar to Rabin's [13] results the current study exhibited a larger variability in small letter CS measures compared with VA. After taking account of this variability using z-scores, small letter CS still differentiated between early cataract and control better than VA

(2.73 for small letter CS versus 2.19 for VA). The greater sensitivity of the small letter CS test compared to VA in cataract is probably due to the steepness of the CS curve at high spatial frequencies, so that a reduction in VA should be associated with a relatively larger reduction in CS [13,15]. The slope of LOCS III nuclear grade vs. small letter CS (0.35) was also considerably steeper than those of LOCS nuclear grade vs. the other two tests (0.12 and 0.09, respectively) indicating a greater sensitivity of small letter CS to nuclear cataract grade than the other two measures.

The previous analyses indicate that small letter CS test was found to be much more sensitive to early cataract than VA. However, VA is the standard measurement of vision in any clinical trial, including anti-cataract drug trials. To be of any value small letter CS would have to provide additional information beyond VA about cataract-related vision loss. The stepwise regression analysis indicated that small letter CS did provide such information and in the evaluation of very early cataract (less than LOCS grade 2) would certainly be preferable to a low spatial frequency CS test. Small letter CS has also been shown to be very repeatable [15] and high spatial frequency CS correlates with some aspects of cataract patients' symptoms [2,6]. However, small letter CS was very strongly correlated with VA ($r^2 = 0.70$) and the extra information provided beyond VA is small (small letter CS increased the amount of variability in nuclear cataract grade accounted for from 47% to 59%). This may limit it's usefulness in the evaluation of early cataract.

In summary, this study confirmed previous findings that in early cataract, high spatial frequency CS (assessed in this study by small letter CS) is preferentially affected, with relatively little reduction in low frequency (or large letter) CS. This confirms reports that measuring low spatial frequency CS or large letter CS such as measured with the Pelli–Robson chart is of little value in very early cataract such as used in anti-cataract drug trials. Other reports suggest that large letter CS measurement is valuable in the assessment of the later stages of cataract [23,19,5]. The results indicated that small letter CS is very sensitive to early cataract, much more so than large letter CS and VA. However, given that VA is the standard measurement in any clinical situation and the finding of a very high correlation between small letter CS and VA, the usefulness of small letter CS measurement in early cataract appears limited. Small letter CS is highly unlikely to provide more useful information in the later stages of cataract, as such subjects will not be able to see any of the letters. For example, any patient with cataract degrading visual acuity worse than 6/9 would be unable to see any of the letters of the small letter (0.2 logMAR or 6/9) CS test used in this study.

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